

# Direct Aerosol Forcing: Calculation from Observables and Sensitivities to Inputs

Allison McComiskey<sup>1,6</sup>, Stephen E. Schwartz<sup>2</sup>, Beat Schmid<sup>3</sup>, Hong Guan<sup>4</sup>, Paul Ricchiazzi<sup>5</sup>, Ernie R. Lewis<sup>2</sup>, John A. Ogren<sup>6</sup>

<sup>1</sup>Cooperative Institute for Research in the Environmental Sciences, University of Colorado, Boulder, CO; <sup>2</sup>Brookhaven National Laboratory, Atmospheric Sciences Division, Upton, NY; <sup>3</sup>PNNL

<sup>4</sup>NASA Ames; <sup>5</sup>Institute for Computational Earth System Science, University of California, Santa Barbara, Santa Barbara, CA; <sup>6</sup>Global Monitoring Division, National Oceanic and Atmospheric Administration, Boulder, CO

## Abstract

Understanding sources of uncertainty in estimating aerosol direct radiative forcing (DRF), the difference in a given radiative flux component with and without aerosol, is essential to local shortwave radiative closure and to quantifying changes in Earth's radiation budget through time. We examine the uncertainty of DRF due to uncertainty in the quantities on which it depends: aerosol amount, aerosol optical properties, i.e., single scattering albedo and asymmetry parameter, and situational variables, i.e., solar geometry and surface albedo, and the wavelength dependencies of these quantities.

## Objectives:

- To determine the uncertainty in forcing as a consequence of uncertainties in the aerosol and surface parameters examined here: optical depth ( $\tau$ ), single scattering albedo ( $\omega_0$ ), asymmetry parameter ( $g$ ), and surface albedo ( $\alpha_s$ ).
- How well can we determine the aerosol Direct Radiative Forcing (DRF)?
- How well do we need to know DRF for accurate climate predictions?
- Where can improvements in measurement of aerosol and environmental variables be made to best increase accuracy in DRF and climate predictions?
- Do different radiative transfer models have a significant effect on our ability to determine aerosol DRF accurately?

## Approach

We calculate aerosol direct radiative forcing (DRF) based on the radiative forcing efficiency ( $e$ ) and a given aerosol optical depth ( $\tau_a$ ):

$$DRF = e\tau_a$$

We then determine the sensitivity ( $S_i$ ) of the DRF to the uncertainty in the property of interest ( $p_i$ ) and its measurement uncertainty ( $\Delta p_i$ ).  $\Delta p_i$  used here is an estimate for all measurement techniques.

$$S_i = \frac{\partial DRF}{\partial p_i} \Delta p_i$$

	$\Delta$
$\tau$ (550 nm)	0.01
$\alpha_s$ (550 nm)	0.03
$g$ (550 nm)	0.05
$\alpha_s$ (UV)	0.05
$\alpha_s$ (IR)	0.05

Last we calculate the total uncertainty in DRF ( $\Delta DRF$ ) due to all properties by summation in quadrature ( $\Sigma^2$ ):

$$\Delta DRF = \sum_i S_i = \sum_i \frac{\partial DRF}{\partial p_i} \Delta p_i$$

## Scenarios

Calculations are made for three sites:

Tropical Western Pacific (TWP) - 0.5°N

Southern Great Plains (SGP) - 36.6°N

North Slope of Alaska (NSA) - 71.3°N

and for the three scenarios described below, representing diverse radiative environments:

A Base Case for each site was chosen to describe typical aerosol properties at each site. These values are used in calculating wavelength dependencies of the properties and in the calculation of  $S_i$ , which is  $\pm 1\Delta p_i$  from base case.

Base Cases	TWP	SGP	NSA
$\tau_a$ (550 nm)	0.05	0.1	0.05
$\omega_0$ (550 nm)	0.97	0.95	0.95
$g$ (550 nm)	0.8	0.6	0.7
$\alpha_s$ (UV)	0.05	0.1	0.9
$\alpha_s$ (IR)	0.05	0.4	0.8
$\bar{a}_{\text{surf}}$	0.5	1.0	1.5
$\bar{a}_{\text{veg}}$	1.0	1.0	1.0

## Radiative Transfer Models

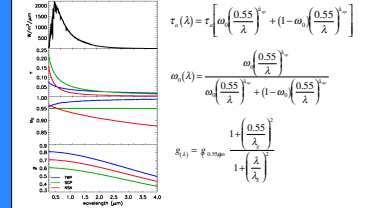
Two models, the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) and Rapid Radiative Transfer Model (RRTM), were run for each case in as model intercomparison exercise. Both use DISORT and have been run with identical parameters using 8 streams, a spectral range from 0.25 - 4.0  $\mu\text{m}$ , the Gueymard solar spectrum, and the follow standard atmospheric profiles:

Case	Atmosphere	H <sub>2</sub> O (g cm <sup>-2</sup> )	Total O <sub>3</sub> (atm-cm)	Below 10 km O <sub>2</sub> (atm-cm)
TWP	Tropical	4.117	0.253	0.0216
SGP	US62	1.418	0.349	0.0252
NSA	Sub-Arctic Winter	0.418	0.486	0.0340

The models differ in their spectral resolution which is 0.005  $\mu\text{m}$  for SBDART. RRTM is run in X bands within the spectral range that are -0.06 - 0.77  $\mu\text{m}$  wide. Aerosol vertical density falls off exponentially with height above the surface in both models.

## Wavelength Dependence of Aerosol Properties

Wavelength dependence is calculated for each aerosol and surface property in the wavelength range from 0.25 to 4.0  $\mu\text{m}$ . Dependencies are shown for the three base cases:



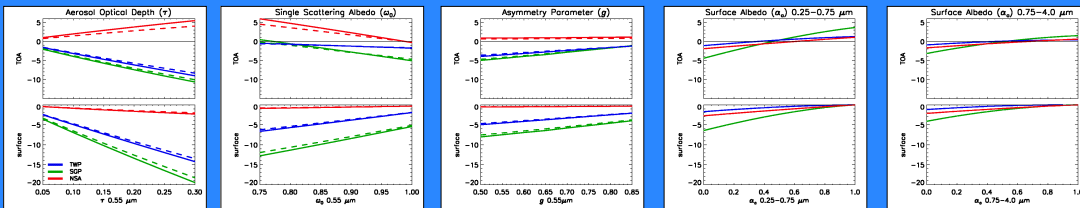
Surface albedo is parameterized as a constant in two wavelength ranges:

$$\alpha_s = (\lambda < 0.75 \mu\text{m}) = c_1$$

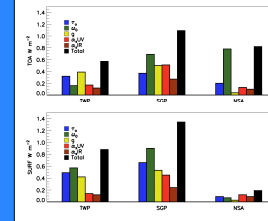
$$\alpha_s = (\lambda > 0.75 \mu\text{m}) = c_2$$

## Scenario 1: Integrated over the shortwave and averaged over SZA for the Equinox

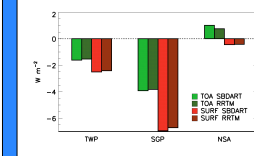
### Direct Radiative Forcing (DRF)



### Sensitivity ( $S_i$ ) for each property and the total uncertainty $\Delta DRF$ (black)



### SBDART and RRTM intercomparison



## Scenario 1 Discussion

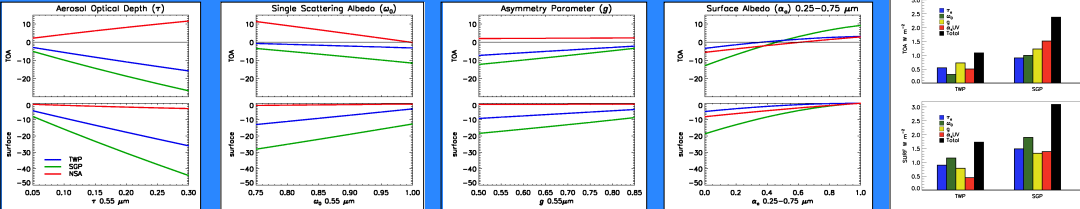
DRF varies linearly with aerosol optical properties. Contribution to variation in DRF is greatest for optical depth, followed by single scattering albedo, asymmetry parameter, then surface albedo.

Model differences are greater than in Scenario 3, possibly due to different SZA averaging schemes.

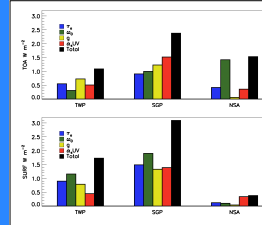
Total uncertainty at the NSA surface is low due to the weak influence of aerosol properties over a high albedo surface, but high at the TOA.

## Scenario 2: 550 nm averaged over SZA for the Equinox

### Direct Radiative Forcing (DRF)



### Sensitivity ( $S_i$ ) for each property and the total uncertainty $\Delta DRF$ (black)



## Scenario 2 Discussion

Results for SBDART only are shown as the RRTM visible band is too wide for comparison.

Patterns in the DRF are the same as in Scenario 1 but the magnitude of the DRF is greater, resulting in higher sensitivities.

Surface albedo shows a greater contribution to changes in DRF at 550 nm at SGP, especially at the TOA, than for DRF integrated over the shortwave.

## Conclusions

Total uncertainties in calculating the aerosol DRF are high; ranging from 0.5 to more than 3 W m<sup>-2</sup> or from ~20-70% of the calculated values for the base cases.

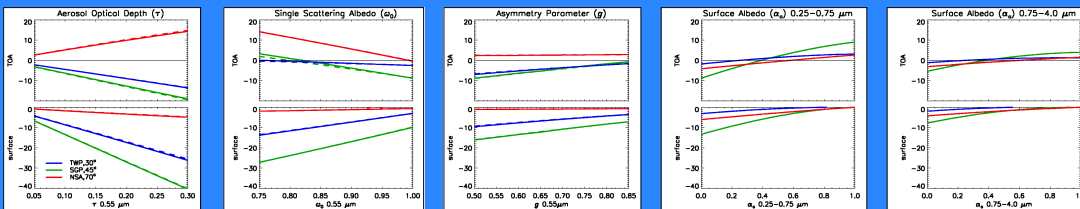
Aerosol optical depth is the strongest driver of changes in aerosol DRF. Sensitivities associated with optical depth are, however, not the highest due to lower measurement uncertainty. Measurement uncertainties are, in general, lower for properties that contribute greater variability to calculated DRF.

Overall, the highest sensitivities are for the single scattering albedo due to the combination of a strong contribution to changes in DRF and a higher measurement uncertainty. Efforts focusing on decreasing uncertainty in measuring single scattering albedo may have the greatest potential for reducing uncertainties in calculated aerosol DRF.

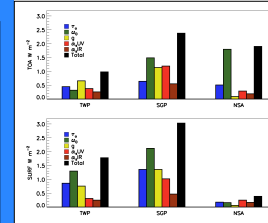
Differences in the two models used here are small compared to total uncertainties in calculated DRF but may be on the order of uncertainties for some individual properties.

## Scenario 3: Integrated over the shortwave and at 30°, 45°, and 70° SZA for TWP, SGP, and NSA respectively

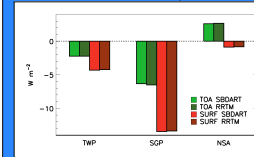
### Direct Radiative Forcing (DRF)



### Sensitivity ( $S_i$ ) for each property and the total uncertainty $\Delta DRF$ (black)



### SBDART and RRTM intercomparison



## Scenario 3 Discussion

Instantaneous DRF calculations are greater in magnitude that average calculations, resulting in larger sensitivities.

Instantaneous DRF calculations are of similar magnitude to those at 550 nm but show a pattern similar to that in Scenario 1.

Model differences are small for instantaneous calculations.